MI-0173

A Possible Strategy for Recycler Orbit Correction

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The Recycler as constructed will have a non-zero closed orbit due to a variety of effects including magnet-to-magnet strength variations, transverse misalignments, and magnet rolls about the longitudinal axes. Tracking studies have shown that it is desirable to produce a closed orbit in the Recycler Ring with an rms value of less than 1 mm and with peak distortions of under 5 mm. Because the Recycler is a fixed energy machine it is possible to consider correcting the closed orbit through transverse motion of the gradient and quadrupole magnets rather than by utilizing a set of powered dipole correctors. The purpose of this note is to describe an investigation into a particular strategy for utilizing a finite number of magnet moves to correct the Recycler orbit to an acceptable level in the presence of expected strength variation and alignment errors.

Ten sets of Recycler closed orbits were generated using random distributions of strength and alignment errors with rms widths as given in Table 1. Errors were generated in Gaussian distributions cut off at 3σ. The equality of the magnet-to-magnet and roll distribution widths implies that the vertical and horizontal orbits will be the same in a statistical sense. As a result only the horizontal orbit is studied here. Results should apply equally well to the vertical orbit.

Table 1: RMS strength and misalignment errors used in closed orbit simulations.

Quantity	Distribution rms width
Magnet-to-magnet strength variation, σ_{BL}/BL	5.0×10^{-4}
Transverse alignment variation, $\sigma_{H,V}$	2.5×10^{-4} meters
Roll variation around longitudinal axis, σ_{ϕ}	5.0×10^{-4} radians

Magnet Moving Algorithm

For each generated closed orbit an algorithm is applied to select a set of magnet moves that reduce the rms orbit distortion. The algorithm employed, to the best of my knowledge, originated in the CERN SPS. The algorithm is as follows:

1. For the closed orbit given, find the single magnetic element in the ring for which a move minimizes the rms orbit distortion. If an element has to be moved more than 5 mm in order to minimize the distortion that element is removed from consideration.

2. Find the second element, that paired with the element identified in 1, is most effective in minimizing the rms orbit distortion. Again reject any element that requires a move of more than 5 mm to minimize the orbit distortion.

3. Repeat up to 15 times, always identifying the element to add to the previously defined list as most effective at minimizing the rms orbit distortion.

Figures 1 and 2 demonstrate the effectiveness of this algorithm. The light curve shows the horizontal closed orbit prior to correction while the heavy curve shows the orbit following application of magnet moves as determined by the above algorithm. The two figures bracket the range of the ten orbits generated--Figure 1 displays the orbit with the largest, and Figure 2 the orbit with the smallest, rms distortion before correction. It should be noted that for this exercise the closed orbit is defined via the beam positions measured at horizontal beam position monitors (BPMs) located downstream of each set of focusing combined function magnets, and that all combined function and quadrupole magnets are candidates for being moved.

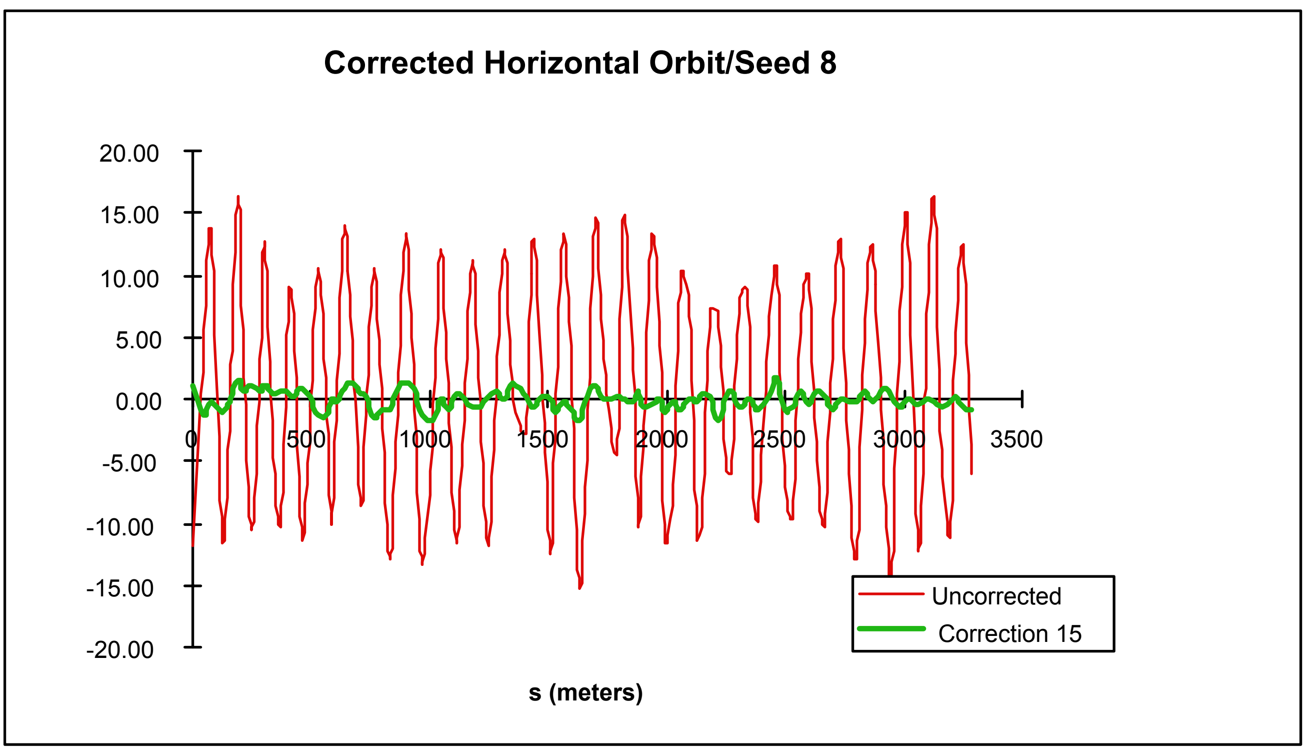

Figure 1: Closed orbit distortion before and after correction for the uncorrected orbit with the largest uncorrected rms orbit error. The correction is achieved by moving 15 magnets with a maximum move of 2.69 mm.

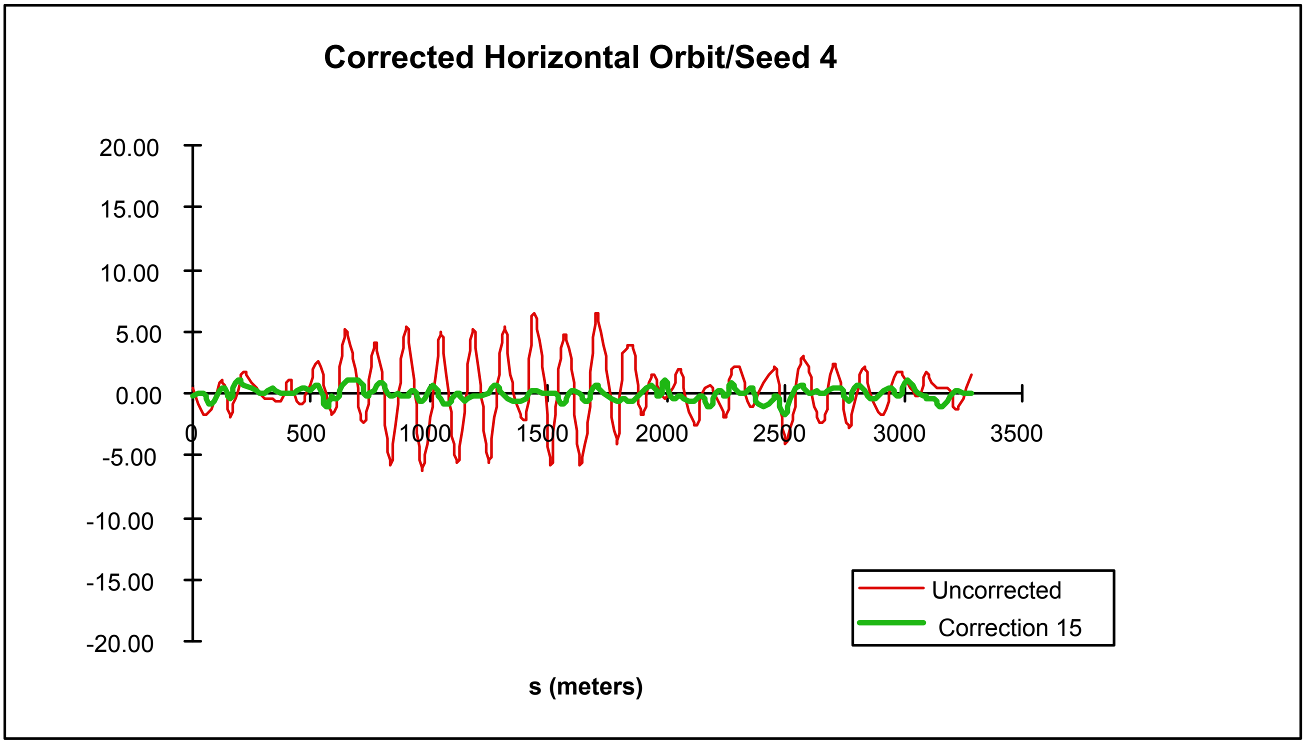

Figure 2: Closed orbit distortion before and after correction for the uncorrected orbit with the smallest uncorrected rms orbit error. The correction is achieved by moving 15 magnets with a maximum move of 3.28 mm.

As can be seen from the figures an rms orbit distortion under a millimeter, with peaks less than 5 mm, can be readily obtained. Table 2 is a compilation of the effectiveness of the algorithm for all ten randomly generated horizontal closed orbits. The table lists the rms and peak orbit distortion before correction, the rms and peak orbit distortion after correction via 15 magnet moves, and the maximum transverse magnet moved required. All corrected orbits are characterized by rms distortions well under a millimeter with peaks typically in the 1.5-2.5 mm range. The maximum magnet move required for any of these corrections is 3.3 mm.

The effectiveness of a smaller number of magnet moves is displayed in Figure 3. In this figure the orbit associated with seed 8, the uncorrected orbit with the largest rms deviation of those studied, is displayed as a function of the number of magnets moved. Both peak and rms orbit distortion are given. The figure shows that an rms of 1 mm is achieved in this case with ten magnet moves.

Table 2: Uncorrected and corrected orbit distortions for ten different randomly generated closed orbits. The column label "Δ_{max}" lists the maximum magnitude of the 15 magnet moves required to effect the correction.

Seed	Uncorrected		Corrected (15 moves)		
	σ_H (mm)	Peak (mm)	σ_H (mm)	Peak (mm)	Δ_{max} (mm)
1	2.87	6.85	0.65	2.61	2.54
2	5.69	13.45	0.66	2.17	2.23
3	7.83	17.57	0.65	2.04	2.80
4	2.69	6.35	0.52	1.66	3.28
5	7.55	17.27	0.75	2.04	2.72
6	2.49	6.02	0.73	2.08	3.06
7	6.06	11.01	0.56	1.52	2.89
8	9.00	16.40	0.73	1.79	2.69
9	5.67	11.33	0.77	1.84	2.82
10	3.69	8.87	0.59	1.77	2.06

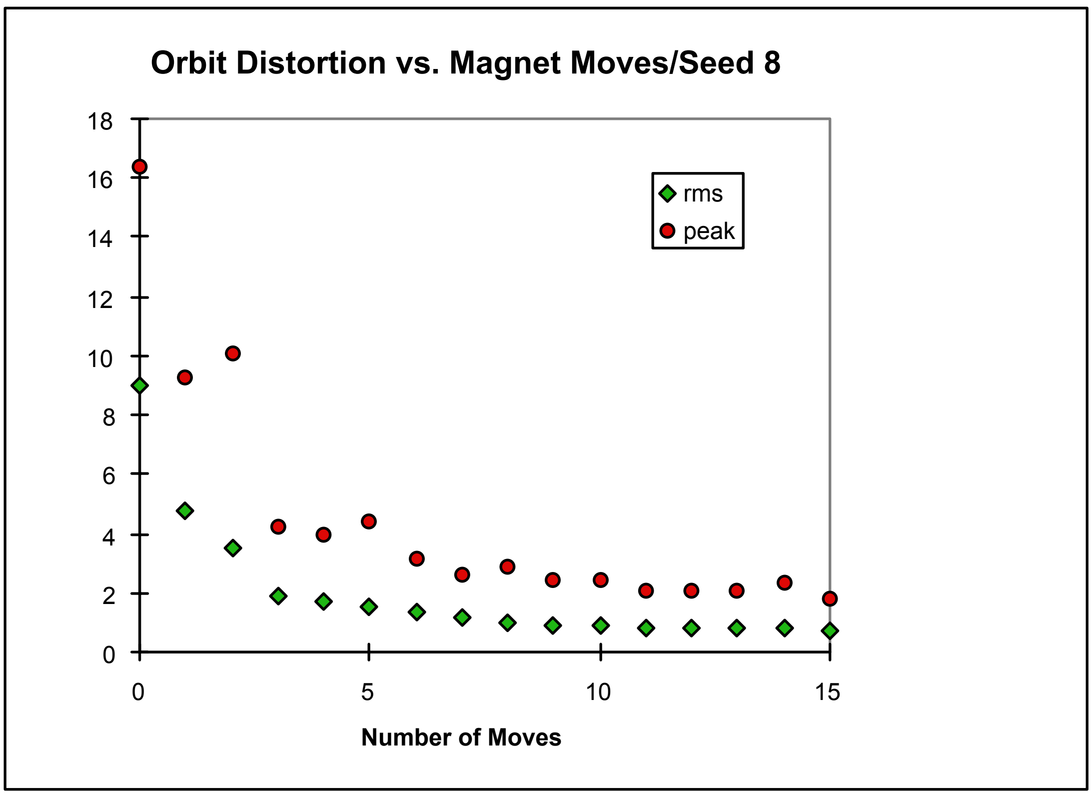

Figure 3: Peak and rms orbit distortion achieved for seed 8 as a function of the number of magnets moved.

Tune vs. Corrected Orbit

Because the long combined function magnets have a sextupole component incorporated into their design field, moving these magnets can affect the tune of the machine by modifying the local quadrupole field seen along the closed orbit. This effect has been calculated for the ten closed orbits already described. Figure 4 displays the difference between the tune on the uncorrected and corrected horizontal closed orbit for each of the orbits examined. Orbits are labeled by their seed (see Table 2). The horizontal tune shift is shown in the figure. The vertical tune shift is nearly the same in each case. This should not be surprising since the sextupole fields are designed to produce an equal chromaticity contribution in each plane. Tune shifts of up to .025 are observed, with .005 more typical. These shifts are significant and will required resetting of tunes following significant orbit changes.

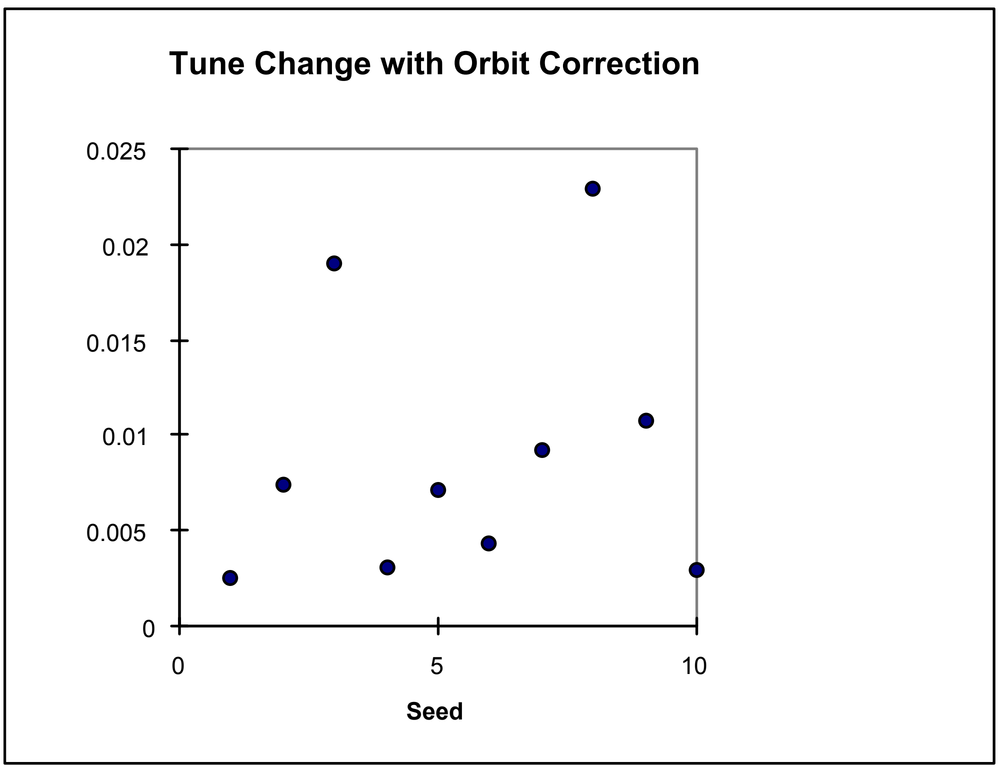

Figure 4: The difference between the horizontal tune on the uncorrected and corrected closed orbits for the ten orbits studied. Orbits are identified by their seed index and correspond t the indices listed in Table 2.

A similar effect will arise from correction of the vertical orbit distortion via vertical magnet moves, except the impact is on the coupling not the tune. This effect is not specifically analyzed here. However, for a random orbit error and the H-V symmetry in the Recycler lattice one would expect the minimum tune split characterizing such coupling to be about equal the tune change given in the figure. Again this implies that coupling adjustment will need to be done following significant adjustment to the closed orbit.

It is worth noting that neither of these effects is a direct result of incorporating a sextupole component in the combined function magnets. Similar effects would result from orbit changes in the presence of a lumped sextupole system for chromaticity correction.

Conclusions

Adjustment of the Recycler orbit through physical movement of combined function and quadrupole magnets appears to be effective. Corrected orbit distortions of less than 1 mm are obtainable with movement of 15 (out of a possible 432) magnets or less. The range of motion required is well within limits thought to be imposed by mechanical support and vacuum systems.

It is assumed that dedicated active correction elements will be provided in the injection and extraction regions.